DEPARTMENT OF ENERGY	LESSON PLAN
	Course: Radiological Control Technician Unit: Site Academics Lesson: 2.04 Dosimetry

Learning Objectives:

2.04.01 Identify the DOE external exposure limits for occupational workers.

2.04.02 Identify the DOE limits established for the embryo/fetus of a female occupational worker.

☞ 2.04.03 Identify the administrative exposure control guidelines at your site, including those for the:

a. Radiation worker
b. Non-radiation worker
c. Incidents and emergencies
d. Unborn child of a female occupational worker.

☞ 2.04.04 Identify the requirements for a female radiation worker who has notified her employer in writing that she is pregnant.

2.04.05 Determine the theory of operation of a thermoluminescent dosimeter (TLD).

2.04.06 Determine how a TLD reader measures the radiation dose from a TLD.

2.04.07 Identify the advantages and disadvantages of a TLD.

☞ 2.04.08 Identify the types of beta-gamma TLDs used at your site.

☞ 2.04.09 Identify the types of neutron TLDs used at your site.

☞ 2.04.10 Determine the requirements for use of TLDs used at your site.

☞ 2.04.11 Determine the principle of operation, and the types used, for the personnel neutron dosimeters used at your site.

☞ 2.04.12 Determine the principle of operation of self-reading dosimetry (SRD) used at your site.

☞ 2.04.13 Determine the principle of operation, and guidelines for use, for the alarming dosimeters used at your site.

☞ 2.04.14 List the types of bioassay monitoring methods at your site.

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; Pacific Radiation Press; 1983

2. **ANL-88-26** (1988) "Operational Health Physics Training"; Moe, Harold; Argonne National Laboratory, Chicago

3. **DOE/EH-0256T Revision 1** (April 1994) "U.S. Department of Energy Radiological Control Manual"

4. **10 CFR Part 835** (December 14, 1993) "Occupational Radiation Protection; Final Rule"; Federal Register; Vol. 58, No. 238

Instructional Aids:

Overheads, overhead projector/screen, chalkboard/whiteboard

LESSON PLAN	INSTRUCTOR'S NOTES
I. LESSON INTRODUCTION	
A. Self Introduction	
1. Name	
2. Phone number	
3. Background	
B. Motivation	
1. This lesson will introduce the types of instruments used to measure EXTERNAL radiation to people. These types of instruments are called DOSIMETERS. There are several types of dosimeters in use worldwide. This material is valuable to all Radiological Protection personnel since dosimeters are the only direct method to measure and document personnel radiation exposure and ensure regulatory compliance with applicable limits.	
C. Overview of Lesson	
1. DOE exposure limits	
2. Site exposure limits	
3. TLD theory	
4. Site TLD usage	
5. Site supplementary dosimeter usage	
6. Site bioassay program	
D. Introduce Objectives	O.H.: Objectives
II. LESSON OUTLINE	
A. DOE ADMINISTRATIVE CONTROL LEVELS AND DOSE LIMITS	
1. Administrative Control Level	RCM Article 211
a. Administrative control level of 2,000 mrem per year is established for all DOE facilities.	
b. A lower administrative control level shall be established by each facility and reevaluated annually.	

LESSON PLAN	INSTRUCTOR'S NOTES
c. 500 mrem/yr should be challenging and achievable, in most cases - 1500 mrem/yr is not sufficiently challenging.	
2. Lifetime Control Level	RCM Article 212
a. Set at N rem, where N is the age of the individual in years.	
b. Special Control Levels are established for individuals with doses exceeding N rem.	
c. For intakes prior to January 1, 1989 - internal contribution should be calculated in terms of cumulative annual effective dose equivalent or committed effective dose equivalent.	
3. Radiological Worker Dose Limits	Objective 2.04.01 RCM Article 213
a. Annual dose limits not to be exceeded:	See Table 1 - "Summary of Dose Limits"
1) Whole body - 5 rem	
2) Lens of eye - 15 rem	
3) Extremity - 50 rem	
4) Any other organ or tissue (other than lens of the eye) and skin - 50 rem	
b. Radiological workers from other DOE sites may receive occupational exposure if:	
1) Provide current RW I or II training records.	
2) Receive site-specific training.	
3) Provide appropriate radiation dose records.	
4. Visitor Dose Limit	RCM Article 214
a. Limited to 100 mrem from the sum of internal and external radiation sources.	See Table 1 - "Summary of Dose Limits"
5. Special Control Levels	RCM Article 216
a. Established for monitored persons with a lifetime occupational dose exceeding N rem.	

b. Shall not exceed 1 rem and should allow the individual's lifetime occupational dose to approach N rem as additional exposure is received.

6. DOE Embryo/Fetus Dose Limits — Objective 2.04.02; RCM Article 215

a. After written notification, for fetal/embryo protection, she is considered a declared pregnant worker.

b. Declaration may be revoked by worker.

c. Mutually agreeable job options shall be provided, without penalty to the worker.

d. Limits for workers continuing radiological work:

1) Gestation period - 500 mrem — See Table 1 - "Summary of Dose Limits"

2) Avoid exceeding 50 mrem/month

3) When the 500 mrem has already been exceeded, the should be reassigned where no additional exposure may be incurred.

B. SITE ADMINISTRATIVE GUIDELINES

1. Radiological Workers — Objective 2.04.03.a

(Insert site specific information here)

2. Non-Radiation Worker — Objective 2.04.03.b

(Insert site specific information here)

3. Exposure from Incidents or Emergencies

a. Exposures up to 2 times the annual dose limits could by permitted to protect against property loss. — 10 CFR Part 835

b. Exposures up to 5 times the annual dose limits or greater, could be permitted to save lives and protect public health.

(Insert site specific information here) — Objective 2.04.03.c

4. Site Exposure Requirements for the Unborn Child

(Insert site specific information here)

Objective 2.04.03.d
Objective 2.04.04

C. TYPES OF DOSIMETRY

1. As a result of irradiation, some solid substances undergo changes in some of their physical properties.

2. These changes amount to storage of the energyfrom the radiation.

3. Since the energy is stored, these materials can be used for dosimeters. The features that have been studied include:

   a. Optical density changes involve a change in the color of some types of plastics and glass. In glass, the dose range is 10^3 to 10^6 rads. The range for plastics is 10^6 to 10^9 rads.

   These high ranges make this medium useless for personnel dosimeters.

   b. Radiophotoluminescence

      1) Radiophotoluminescence is the property of certain glasses (silver-activated phosphate glass) to store the energy from radiation until the glass is exposed to ultraviolet light, at which time the energy is released in the form of orange light. A fluorimeter (which is very expensive) is used to measure the light output.

      2) The dose response with this method is quite good, but these types of dosimeters have not received wide acceptance in this country. They are, however, used extensively in Japan and Europe.

   c. Conductivity changes - Very little has been done with the use of semiconductors for dosimetry applications. One reason for this is a low sensitivity of about 10 rads.

   d. Thermoluminescence - The property of thermoluminescence of some materials is the main method used for personnel dosimeters at DOE facilities and will be discussed in further detail.

D. THEORY OF OPERATION OF THERMOLUMINESCENT DOSIMETERS (TLD)

1. Thermoluminescence is the ability of some materials to convert the energy from radiation to a radiation of a different wavelength, normally in the visible light range. There are two categories of thermoluminescence.

    a. Fluorescence - This is emission of light during or immediately after irradiation (within fractions of a second) of the phosphor. This is not a particularly useful reaction for TLD use.

    b. Phosphorescence - This is the emission of light after the irradiation period. The delay time can be from a few seconds to weeks or months. This is the principle of operation used for thermoluminescent dosimeters.

2. TLD's use phosphorescence as their means of detection of radiation.

    Objective 2.04.05

    a. Electrons in some solids can exist in two energy states, called the valence band and the conduction band. The difference between the two bands is called the band gap.

    b. Electrons in the conduction band or in the band gap have more energy than the valence band electrons.

    c. Normally in a solid, no electrons exist in the energy states contained in the band gap. This is a "forbidden region."

    d. In some materials, or if impurities are added, defects in the material exist or are made that can trap electrons in the band gap and hold them there. These trapped electrons represent stored energy for the time that the electrons are held. This energy is given up if the electron returns to the valence band.

    See figure 1 - "Electron Entrapment"

LESSON PLAN	INSTRUCTOR'S NOTES
e. In most materials, this energy is given up as heat in the surrounding material, however, in some materials a portion of energy is emitted as light photons. This property is called luminescence.	See figure 2 - "Thermoluminescence"
E. OBTAINING RESULTS FROM TLDs	Objective 2.04.06
1. Basic principle of operation	
a. Heating of the TL material causes the trapped electrons to return to the valence band. When this happens, energy is emitted in the form of visible light.	
b. The light output is detected and measured by a photomultiplier tube and a dose equivalent is then calculated.	
c. A typical basic TLD reader contains the following components:	See figure 3 - "TLD Reader"
1) Heater	
2) Photomultiplier tube	
3) Meter/recorder	
2. Glow curve	See figure 4 - "Glow curve"
a. Obtained from heating process.	
b. The light output from TL material is not easily interpreted. At least two peaks result.	
1) As the material is heated, electrons trapped in "shallow" traps are released. This results in a peak as these traps are emptied. The light output drops off as these traps are depleted.	
2) As heating continues, the electrons in deeper traps are released. This results in a second peak (typically larger than the first one) which is used to calculate the dose equivalent. The area under the curve is used for this calculation.	

c. After the readout is complete, the TLD is annealed at a high temperature. This process essentially zeroes the TL material by releasing all trapped electrons. The TLD is then ready for reuse.

F. ADVANTAGES AND DISADVANTAGES OF TLDs — Objective 2.04.07

1. Advantages (primarily as compared to film badges)
   a. Able to measure a greater range of doses.
   b. Doses may be easily obtained.
   c. They can be read on site instead of being sent away for developing.
   d. Quicker turnaround time for readout.
   e. Reusable.
2. Disadvantages
   a. The readout process effectively "zeroes" the TLD.

G. SITE BETA/GAMMA TLDs — Objective 2.04.08

(Insert site specific information here)

H. SITE NEUTRON TLDs — Objective 2.04.09

(Insert site specific information here)

I. DOE RCM EXTERNAL DOSIMETRY REQUIREMENTS — RCM Article 511

1. Required for the following: — Limits established in Table 1 - "Summary of Dose Limits"
   a. Expected whole body dose > 100 mrem; or > 10% of limits for extremities, organs, and other tissues.
   b. Declared pregnant worker expected to receive 50 mrem or more during the gestation period.
   c. Minors and students, visitors and public expected to receive 50 mrem or more in a year.
2. Neutron dosimetry required for persons exceeding 100 mrem from neutrons annually.

3. Issue by qualified personnel and worn only by assignee.
4. Dosimeter use should be minimized and only issue to personnel requiring their use.
5. Dosimeters shall be returned at required intervals. Personnel not returning dosimeters should be restricted.
6. Primary dosimeters shall be worn on the chest area or between the waist and the neck.
7. Personnel shall not be assigned multiple dosimeters; and avoid exposure of dosimeter to non-occupational sources.
8. When dosimeters are lost, damaged, or contaminated, personnel should place work in a safe condition, exit and notify the RCO. Reenter only after review and approval.

J. SITE REQUIREMENTS FOR USE OF TLDs — Objective 2.04.10

(Insert site specific information here)

K. SITE PERSONNEL NEUTRON DOSIMETERS — Objective 2.04.11

(Insert site specific information here)

L. POCKET AND ELECTRONIC DOSIMETERS — RCM Article 513

1. Provide real time dose indication.
2. Supplemental dosimeters shall be issued:
   a. High Radiation or Very High Radiation Area entry.
   b. Could exceed 10% of an administrative control level in one work day.
   c. Required by RWP.
3. Worn with primary dosimetry and located on chest area, on or between the waist and the neck.
4. Shall be read periodically and should not exceed 75% of full scale.
5. RWP authorized work shall cease when supplemental dosimeter indicates exposure or exposure rate is > than expected.

6. When supplemental dosimeters differ by more than 50% from primary dosimeters and the primary result is >100 mrem, an investigation should be initiated.

M. SITE SELF-READING DOSIMETERS

(Insert site specific information here) — Objective 2.04.12

1. Self Reading Pocket Dosimeters (SRPD) — See figure 5 - "SRPD"
   a. Direct reading ion chamber.
   b. Utilizes two electrodes: — See figure 6 -"SRPD Reading"
      1) Fiber electrometer (fixed and moveable components)
      2) Metal frame
   c. As chamber is ionized the charge is decreased on the movable and fixed fiber.
   d. The movement of the fiber is proportional to the dose received.

N. SITE ALARMING DOSIMETRY

(Insert site specific information here) — Objective 2.04.12

O. DOE REM INTERNAL DOSIMETRY REQUIREMENTS — RCM Article 521

Re-enforce difference between "internal" and "external" dose

1. The following personnel shall participate:
   a. Personnel entering RBAs - 100 mrem, committed effective dose equivalent.
   b. Declared pregnant workers - 50 mrem, during gestation period.
   c. Minors/students, visitors/public - 50 mrem, committed effective dose equivalent.
2. Estimation shall be based on bioassay results rather than air concentration values.

3. Follow-up bioassay monitoring is required when results indicate a committed effective dose equivalent of 100 mrem or more.
4. A bioassay program should be considered for personnel routinely exposed to surface or airborne contamination or to radionuclides readily absorbed through the skin.
5. Personnel are required to submit bioassay samples.
6. Personnel shall be notified of positive bioassay results.

P. BIOASSAY ASSESSMENT METHODS

1. General
   a. Today's technology has not produced a device that allows accurate determination of internal exposure following the entry of radioactive materials into the body.
   b. The method that is used to determine internal dose contributions relies on calculation of dose to affected portions of the body based on the quantities of radioactive materials in the body. Thus, the real problem becomes one of quantifying the amount of material present.
   c. Bioassay is the term that is used to describe the assessment of the quantity of radioactive material present in the body. There are currently two types of bioassay measurements employed in nuclear industries:
      1) In vivo - analysis of living tissue.
      2) In vitro - analysis of excreted samples.
   d. Bioassay programs are designed to fulfill two needs:
      1) Evaluate effectiveness of contamination control practices.
         a) Routine bioassay programs utilize submission and analysis of samples from workers in facilities where the likelihood of intake exists.

b) Primarily limited to urinalysis due to ease of sample collection.

c) Also includes initial, routine, and termination whole body counts.

2) Evaluate potential consequences of accidental inhalation or ingestion of large quantities of radioactive materials.

a) Can involve all types of bioassay measurements with collection and analysis of nasal, urine, and fecal samples.

b) Whole body counts provide immediate indications for given isotopes if individual(s) involved are free of contamination.

2. In vivo measurements

a. The amount of materials is estimated by counting radiation emitted by radioactive materials in the body.

b. Only good for radioactive materials which emit gamma radiation of sufficient abundance and energy to be statistically detected and measured.

c. With use of expensive, sophisticated spectroscopy, most contributors (isotopes present) can be identified.

d. Facility In vivo methods

(Insert site specific information here) Objective 2.04.14

e. Advantages

1) No sample required.

2) Results obtained quickly.

3) Some equipment design allows field use.

4) Time and manpower requirements minimized.

f. Disadvantages

1) Limited to detection and measurement of gamma emitters.

2) Individual must be free of contamination.

3) Long count times for identification.

4) Effects of background.

5) Complex calibration procedure and calibration equipment.

6) Expense.

7) Quantification error due to differences in tissue structure from one person to another as compared to calibration phantom.

3. In Vitro Measurements

a. The amount of material present in the body is estimated using the amount of materials present in excretions or secretions from the body, or samples from the body, or samples removed from the body.

b. Samples could include urine, blood, breath, sputum, sweat, saliva, hair, nasal discharges, tissue and feces.

c. Calculation requires knowledge of and use of metabolic models which allow use of activity in samples to be related to activity present in the body.

d. Resulting dose calculations to quantify committed and effective dose equivalents are estimates.

1) This is due partly to use of default values for measurements that cannot be readily made such as mass of particular organs, volumes of particular fluids, etc., in lieu of actual values for individual involved. Remember that reference man is an average.

2) Another contributing factor is difference metabolism from one individual to another.

e. Facility In vitro methods

(Insert site specific information here) Objective 2.04.14

f. Advantages of in vitro measurements

1) Can be used for estimation of neutron doses using activation product concentration in hair and blood (P^{32} and Na^{24}).

2) Can be used to quantify presence of materials which decay by alpha and beta emission to allow detection and measurement with external detector systems.

g. Disadvantages

1) Requires sample submission and analysis.

2) Time and manpower requirements.

3. Bioassay Scheduling Program

a. Contamination found in a given facility will depend on the materials that are used and produced in the facility. Thus, the materials that internal dosimetrists are primarily concerned with will change from one facility to another as well.

b. Baseline/Routine/Exit Evaluations

(Insert site specific information here)

c. Special Evaluations

(Insert site specific information here)

d. Investigation Levels

(Insert site specific information here)

e. Medical Uses

(Insert site specific information here)

III. SUMMARY

A. Review major topics

1. DOE exposure limits

2. Site exposure limits

3. TLD theory
4. Site TLD usage
5. Site supplementary dosimeter usage
6. Site bioassay program

B. Review learning objectives

IV. EVALUATION

Evaluation shall consist of a written examination comprised of multiple choice, fill-in the blank, matching and/or short answer questions. 80% shall be the minimum passing criteria for examinations.